Estuarine, Coastal and Shelf Science 82 (2009) 583–596

Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

journal homepage: www.elsevier.com/locate/ecss

How well do ecosystem indicators communicate the effects of anthropogenic eutrophication?

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ARTICLE INFO

Article history:
Received 22 October 2008
Accepted 16 February 2009
Available online 26 February 2009

Keywords:
eutrophication
Marine Strategy Directive
indicators
time-series

ABSTRACT

Anthropogenic eutrophication affects the Mediterranean, Black, North and Baltic Seas to various extents. Responses to nutrient loading and methods of monitoring relevant indicators vary regionally, hindering interpretation of ecosystem state changes and preventing a straightforward pan-European assessment of eutrophication symptoms. Here we summarize responses to nutrient enrichment in Europe's seas, comparing existing time-series of selected pelagic (phytoplankton biomass and community composition, turbidity, N:P ratio) and benthic (macro flora and faunal communities, bottom oxygen condition) indicators based on their effectiveness in assessing eutrophication effects. Our results suggest that the Black Sea and Northern Adriatic appear to be recovering from eutrophication due to economic reorganization in the Black Sea catchment and nutrient abatement measures in the case of the Northern Adriatic. The Baltic is most strongly impacted by eutrophication due to its limited exchange and the prevalence of nutrient recycling. Eutrophication in the North Sea is primarily a coastal problem, but may be exacerbated by climatic changes. Indicator interpretation is strongly dependent on sea-specific knowledge of ecosystem characteristics, and no single indicator can be employed to adequately compare eutrophication state between European seas. Communicating eutrophication-related information to policy-makers could be facilitated through the use of consistent indicator selection and monitoring methodologies across European seas. This work is discussed in the context of the European Commission's recently published Marine Strategy Directive.

1. Introduction

Eutrophication is widely recognised as a key problem affecting Europe's seas in the technical reports and policy statements of the OSPAR (OSPAR Commission, 2000), Helsinki (HELCOM, 1991), and Black Sea Commissions (Black Sea Commission, 1996), the Mediterranean Action Plan (MAP – UNEP, 1996), and the European Environment Agency (EEA – Ærtebjerg et al., 2001). Additionally, the minimisation of eutrophication effects is specifically mentioned as a requirement of good environmental status in the European Union's Marine Strategy Directive (European Commission, 2008). A causal link between anthropogenic sources of nutrients and the emergence of eutrophication symptoms is generally accepted (Ærtebjerg et al., 2001; Smith, 2006). However, cause–effect relationships are not straightforward as coastal ecosystems respond to nutrient loading in various ways. System-specific attributes may act as a filter to modulate responses to enrichment and a complex suite of direct and indirect responses may interact (Cloern, 2001); in the Black Sea, for example, the combined effects of nutrient loading and overfishing resulted in a trophic cascade which altered the ecosystem's structure and dynamics (Daskalov, 2002). Other sources of environmental degradation, such as toxic substances, overfishing, and invasive species, as well as climate and natural variability, may confound this causality (Caddy, 2000; MacKenzie et al., 2002;

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doi:10.1016/j.ecss.2009.02.017

Nixon and Buckley, 2002; MacKenzie and Koster, 2004; Oguz, 2005; McQuatters-Gollop et al., 2007). Our growing understanding of anthropogenic impact on coastal systems (e.g. Cloern, 2001; Elmgren, 2001) includes recognition of non-linear responses and even regime shifts by entire ecosystems (e.g. Beaugrand, 2004).

From 2012 as a condition of the Marine Strategy Directive, EU Member States must monitor relevant eutrophication indicators in their waters; these indicators are required to be comparable between regions (European Commission, 2008). Monitoring programmes, some underway for decades (Cociasu and Popa, 2004; Wiltshire and Manly, 2004; Richardson et al., 2006), currently record a range of relevant variables for assessment and periodic reporting on the state of Europe's marine environment. This paper examines a selection of commonly reported indicators of ecosystem state, focusing on those used to monitor marine eutrophication. The indicators examined here can be found in Annex III of the Marine Strategy Directive which includes a list of physical, chemical and biological indicators suggested for use in monitoring progress towards good environmental status of marine waters (European Commission, 2008). The aim of our research is therefore to answer the following question: Do the eutrophication-relevant ecosystem indicators suggested in the Marine Strategy Directive provide consistent, scientifically founded information to European policy-makers so that they can understand and compare eutrophication status in Europe's regional seas?

Nutrient enrichment generates two primary, interrelated effects in aquatic ecosystems: firstly, stimulation of phytoplankton growth, and in some cases a change in phytoplankton species composition, favouring opportunistic and even harmful species, in the pelagic zone; and secondly, shading and deposition of organic matter in the benthic zone. Our selection of ecosystem indicators distinguishes between pelagic and benthic ecosystems to capture these primary effects. From the large range of indicators and variables reported in the literature (e.g. Gazeau et al., 2004, which also offers a comparison of Europe's regional seas), we confine ourselves to those for which long data series exist for regions of Europe's seas that suffer from eutrophication: the coastal North Sea, the Baltic Proper, the Northern Adriatic Sea, and the northwest shelf of the Black Sea (Fig. 1). Following a short description of our method, this paper summarizes responses to nutrient enrichment in the regional study areas. We then compare the indicators presented based on their effectiveness in assessing eutrophication effects, and draw implications for policy.

2. Methods

The work presented here was part of the EU FP6-funded European Lifestyles and Marine Ecosystems (ELME) project. One of the objectives of ELME was to gather as much information as possible on well established ecosystem trends that could be used for the future management of Europe's seas. ELME used an 'indicator' approach to exploring change in Europe's seas; although predictive models are highly desirable for management purposes, they must be fed with data, which have their own intrinsic value. Eutrophication was a priority issue of the project and a key product was the aggregation and analysis of existing relevant long-term datasets in European marine and coastal regions where eutrophication is a historical concern. Many of the datasets gathered during ELME coincide with the indicators listed in the Marine Strategy Directive.

2.1. Areas of study

The Baltic Proper forms the central and largest basin of the Baltic Sea. The Baltic Proper is brackish, with a distinct north-to-south salinity gradient, and is the most limited in exchange of the four study areas. Nutrients entering the Baltic have long residence times: between 4.4 and 22.5 years for P in the Baltic Proper (Savchuk, 2005). The Baltic Sea's catchment can be divided into a northern boreal part draining into the Gulf of Bothnia and a south-eastern part draining into the Baltic Proper (Savchuk,

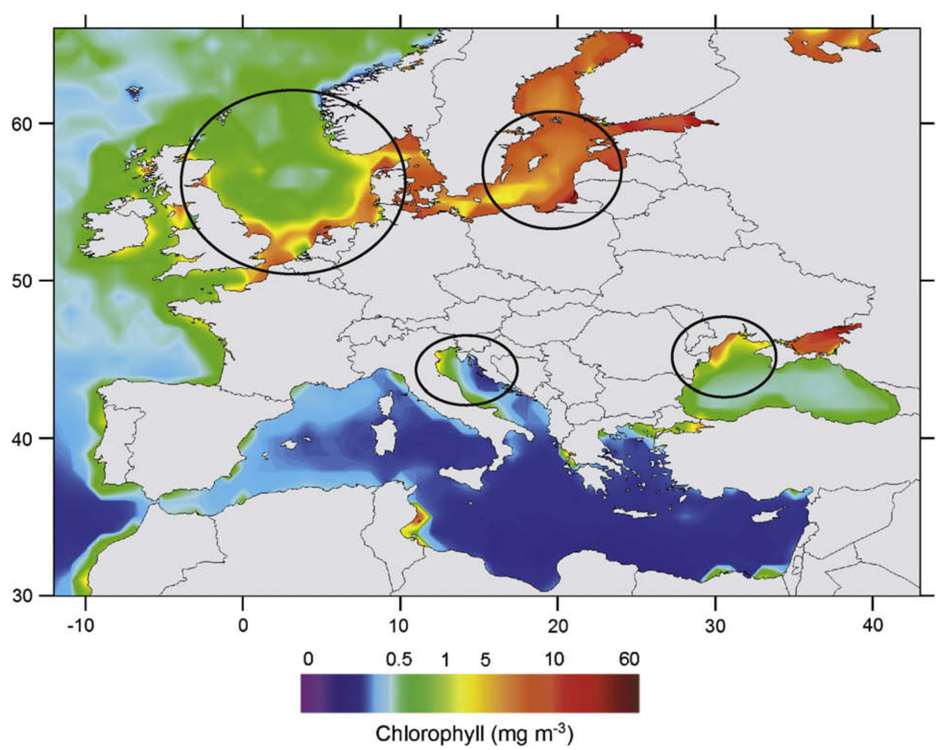

Fig. 1. SeaWiFS (Sea-viewing Wide Field-of-View sensor) remote sensing images showing chlorophyll concentrations in four European regional seas: Baltic, Mediterranean, Black and North – annual composite for 2007. SeaWiFS overestimates chlorophyll in waters with high levels of suspended substances, such as some coastal areas and the Baltic Sea.